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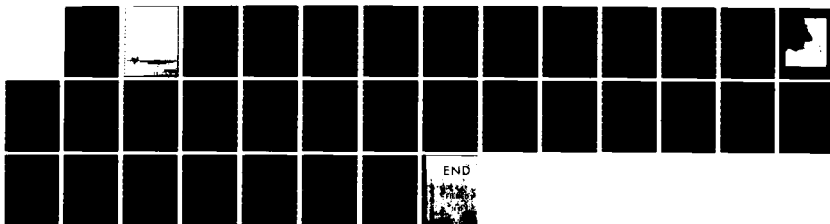
XCP MEASUREMENTS OFF CALIFORNIA IN OCTOBER 1982: CRUISE 1/1  
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**Applied Physics Laboratory University of Washington**  
**Seattle, Washington 98105**

# **XCP Measurements Off California in October 1982: Cruise Report and Preliminary Results**

**Eric A. D'Asaro**

**APL-UW 8310  
12 August 1983**

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### **Acknowledgments**

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## ABSTRACT

✓ Sixty-nine profiles of horizontal velocity and temperature from the surface to about 800 m were made using the Expendable Current Profiler (XCP) during De Steiguer cruise 1212, 7-18 October 1982. The XCP's were deployed in a 6 day time series behind a drogued buoy and in a 275 n.mi. zigzag spatial survey. Satellite infrared images were used to locate a cruise area away from strong mesoscale features. The measurements were designed to estimate the horizontal coherence function of the near-inertial frequency internal wave field for comparison with similar measurements made in the Sargasso Sea. It was found that the near-inertial waves are a dominant feature of the velocity field. Significant coherence exists between nearby profiles. It will, therefore, be possible to compute a correlation function for these data as planned. A near-surface feature with peak-to-peak velocities of 70 cm/s was observed and partially surveyed.

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## INTRODUCTION

This report presents preliminary results from a series of velocity and temperature profiles taken in the California Current during October 1982. These measurements were motivated primarily by the analysis of NORDA-sponsored XCP (Expendable Current Profiler) measurements made in the Sargasso Sea during HYDRO-79. In that analysis, D'Asaro and Perkins (1983) estimated the wavenumber-frequency spectrum and vertical energy flux of internal waves near the inertial frequency using a horizontal survey of XCP profiles and background current meter and CTD observations. Although the near-inertial frequency waves appeared to be forced primarily by the surface wind field, their horizontal scale was much smaller than would be expected from such forcing. This suggests that some environmental parameter, such as the mesoscale eddy field, played an important role in the wave forcing. The measurements described here were designed to duplicate the HYDRO-79 measurements in a different region of the ocean. In addition, these XCP measurements were used to measure upper ocean shear in conjunction with microstructure measurements.

## STRATEGY

Several elements were necessary for a successful measurement of the internal wave field. These elements and the methods used to obtain them are described below.

### Location

The California Current is known to have eddies roughly 100 km in diameter with velocities of up to 20 cm/s. A successful internal wave analysis required that the experiment be located away from such eddies.

Satellite infrared images were used to choose an experimental site. Cold surface water generated by coastal upwelling along the California coast is advected by the offshore eddies and thus traces their structure. The Remote Sensing Facility at the Scripps Institution of Oceanography was contracted to provide satellite images starting 2 weeks before the cruise. Several cloud-free days occurred during this period, and excellent images were obtained. The final area was chosen the day before the cruise. Fortunately, this site did not conflict with Navy operational restrictions and was only slightly more than a day's steaming out of San Diego.

### Time series measurements

Even away from energetic eddies, the geostrophic current off California is about 5 cm/s, sufficiently large to be important in the internal wave analysis. A 13-m-long "window-shade" drogue attached by an 80-m-long line to a surface buoy was used to track



the water below the mixed layer for 5 days and thus estimate the near-surface geostrophic velocity. A time series of XCP profiles was made at the drifting buoy to separate the near-inertial, low frequency geostrophic, and high frequency internal wave components of the velocity field. The sampling was one quarter of an inertial period. This time series also provided shear information for use with the microstructure profiles taken during this time. Because internal waves are advected by the geostrophic flow, a time series following a drifting buoy is much less affected by advection than is a moored time series. Thus, no correction for advection is necessary here, unlike the HYDRO-79 analysis.

### Hydrographic data

The internal wave field depends critically on the oceanic density profile. Several hundred CTD and AMP<sup>1</sup> profiles of temperature and salinity were taken in the upper 200 m near the drifting buoy. Three CTD profiles were made to 600 m. These profiles will allow the mean density profile, the mean T/S relation, and the T/S variability to be computed. In addition, 37 XBT's were launched during the spatial survey to help determine the geostrophic shear in the upper ocean.

### Spatial survey

The major goal of these measurements was to determine the spatial correlation function of the internal wave field near the inertial frequency, using the methods of D'Asaro and Perkins (1983) and D'Asaro (1983). This required a spatial survey of XCP profiles subject to several constraints:

- (1) The survey must cover an area, rather than extend along a line, so that the isotropy of the internal wave field can be observed.
- (2) If the correlation length of the internal wave field is roughly  $\lambda$ , the survey must sample an area much larger than  $\lambda^2$  so that many independent realizations of the internal wave field are sampled.
- (3) The survey must contain probe separations both much smaller and much larger than  $\lambda$  so that the correlation function can be determined for a variety of spatial lags. The small spatial lags and large spatial lags must be about equally distributed throughout the survey.
- (4) Probe pairs separated by short spatial distances, 5 km or less, must be taken at short temporal separations, much less than an inertial period; pairs with

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<sup>1</sup>APL-UW's Advanced Microstructure Profiler

longer spatial separations can have longer temporal separations. This allows "inertial rotation" to be used in the construction of the correlation function (D'Asaro and Perkins, 1983).

- (5) The survey must use only 40 XCP's, assuming a 20% failure rate, and be executable from a single ship within 2 days.

Considerable effort was spent designing sampling patterns. For a fixed number of probes, the primary trade-off is between condition 2, which requires a large pattern for statistical reliability, and condition 3, which requires probes at small separations for an accurate correlation function. An acceptable sampling pattern was required to have at least 10 degrees of freedom at each separation. The degrees of freedom were computed using the methods described by D'Asaro (1983) assuming a correlation scale of 50 km.

Originally, the sampling pattern was designed around the drifting buoy. Once at sea, however, it was found that the radar transponder on the buoy was not properly tuned to the ship's radar. The ship therefore had to stay within 5 km or so of the buoy, making it impossible to execute the survey as planned. Instead, a modified survey was executed after the buoy was recovered.

The XCP survey (Fig. 1) is a zigzag pattern of four equilateral triangles, 32 n.mi. (59 km) on a side, with probe spacings of 16, 8, 4, and 2 n.mi. on each side. The probe drops are clustered together at the triangle vertices, resulting in a wide range of spatial separations with a minimal number of probes and a roughly equal distribution of the small spatial separations over the entire survey.

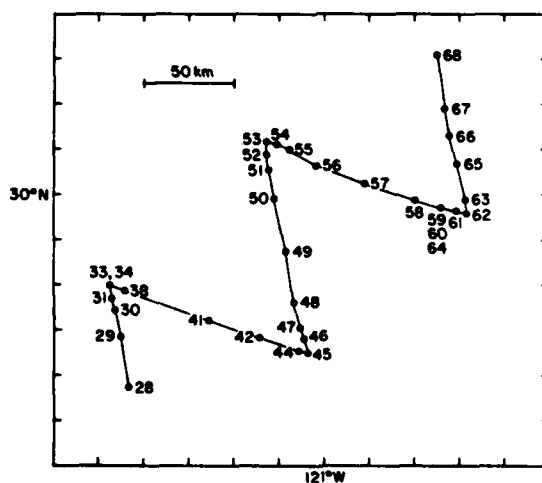


Fig. 1. XCP spatial survey. Identifying numbers are the last two digits of the numbers in Tables I and II.

### CRUISE AND DATA DESCRIPTION

All data reported here are associated with the USNS De Steiguer cruise 1212, 7-18 October 1982. Michael Gregg, chief scientist, directed the microstructure measurements, CTD operations, and the drogued buoy deployment and recovery. XCP's manufactured by the Sippican Corporation were deployed by Eric D'Asaro and Pat McKeown with the assistance of other scientific personnel using standard APL-UW deck gear and procedures (Sanford *et al.*, 1982).

Of the 70 XCP probes taken on board, one was dead, and four were improperly launched. Of the remaining 65 probes, 89% produced usable data and 62% functioned nearly perfectly. This is a somewhat higher failure rate than has typically been found in APL cruises and may partially be due to the use of less experienced personnel in the launching procedure. In particular, data from several probes were lost when a minor variation in the launching procedure resulted in the XCP wire snagging on the launch tube.

The location and times of all XCP deployments are shown in Tables I and II. The first 28 probes were launched within a few hundred meters of the drifting buoy. The remainder of the probes were launched in the spatial pattern shown in Fig. 1.

The drift track of the buoy and the pattern of the spatial survey are shown superposed on a satellite sea surface temperature image in Fig. 2. The experimental area is seen to be in a region of smooth sea surface temperature variation, well away from any obvious eddies. A map of the 15°C isotherm constructed from the XCP and XBT temperature data taken during the spatial survey (Fig. 3) similarly shows no evidence of an eddy. The geostrophic shear between 400 m and the surface estimated from the mean isotherm tilt in Fig. 3 is in rough agreement with the 6 cm/s mean southwesterly drift of the drogued buoy over its 6 day deployment.

The east, north, and temperature data from all XCP profiles are shown in Figs. 4, 5, and 6 respectively. These profiles have been edited both by hand and using the normal XCP noise criterion. A vertical mean was removed from each velocity component. Profiles from the buoy time series are displayed in Figs. 4a, 5a, and 6a. Profiles from the spatial survey are shown in Figs. 4b-e, 5b-e, and 6b-e. In each of these figures the profiles are displaced horizontally so that the origin of the plot corresponds to the time of launch relative to an arbitrary origin, as displayed on the bottom axis. Each profile is identified by the number on the upper axis, which corresponds to the number in Table I with the first two digits removed.

TABLE I. California Current XCP log: time series.

XCP	Year	DROPTIME				POSITION				Comments
		Month	Date	Hrs	Min	Latdeg	Latmin	Longdeg	Longmin	
1000	82	OCT	09	18	38	29 N	54.9	121 W	01.4	good
1001	82	OCT	09	05	05	29 N	50.0	120 W	58.8	250 m, not at buoy
1002	82	OCT	10	08	26	29 N	52.1	121 W	03.2	good
1003	82	OCT	10	18	38	29 N	52.8	121 W	03.7	good
1004	82	OCT	11	00	42	29 N	51.9	121 W	03.5	poor
1005	82	OCT	11	01	00	29 N	51.9	121 W	03.5	good
1006	82	OCT	11	06	55	29 N	51.4	121 W	04.3	fair, bad launch
1007	82	OCT	11	07	14	29 N	51.1	121 W	04.5	good
1008	82	OCT	11	12	50	29 N	51.0	121 W	05.4	good to 300 m
1009	82	OCT	11	18	50	29 N	51.0	121 W	05.4	good
1010	82	OCT	12	00	53	29 N	49.9	121 W	05.4	bad, wire drag
1011	82	OCT	12	01	07	29 N	50.0	121 W	05.4	fair
1012	82	OCT	12	07	05	29 N	49.1	121 W	06.3	good
1013	82	OCT	12	12	57	30 N	07.2	121 W	00.3	fair
1014	82	OCT	12	18	58	29 N	48.8	121 W	07.1	bad, wire drag
1015	82	OCT	13	00	59	29 N	47.9	121 W	07.9	good
1016	82	OCT	13	07	02	29 N	47.3	121 W	08.4	good
1017	82	OCT	13	13	06	30 N	05.2	121 W	02.1	poor
1018	82	OCT	13	13	23	30 N	05.1	121 W	02.3	good
1019	82	OCT	13	19	10	29 N	46.3	121 W	09.8	good
1020	82	OCT	14	01	14	29 N	46.0	121 W	10.1	good
1021	82	OCT	14	07	15	30 N	03.3	121 W	03.9	good
1022	82	OCT	14	13	19	29 N	44.8	121 W	11.7	good
1023	82	OCT	14	19	03	30 N	02.8	121 W	05.3	fair
1024	82	OCT	15	03	03	29 N	42.8	121 W	12.9	good
1025	82	OCT	15	07	46	30 N		121 W		good
1026	82	OCT	15	21	38	29 N	40.6	121 W	15.0	bad
1027	82	OCT	15	21	46	29 N	41.4	121 W	14.7	good

TABLE II. California Current XCP log: survey.

XCP	Year	DROPTIME				POSITION				Comments
		Month	Date	Hrs	Min	Latdeg	Latmin	Longdeg	Longmin	
1028	82	OCT	16	04	58	29 N	01.6	122 W	07.5	good
1029	82	OCT	16	06	41	29 N	16.6	122 W	10.4	good
1030	82	OCT	16	07	35	29 N	24.6	122 W	12.4	good
1031	82	OCT	16	08	07	29 N	28.2	122 W	13.5	fair
1032	82	OCT	16	08	14	29 N	28.5	122 W	13.6	no data
1033	82	OCT	16	08	43	29 N	31.8	122 W	14.1	fair
1034	82	OCT	16	08	55	29 N	32.4	122 W	14.2	poor
1035	82	OCT	16	09	32	29 N	30.7	122 W	9.4	150 m only
1036	82	OCT	16	09	41	29 N	30.5	122 W	9.0	poor
1037	82	OCT	16	09	49	29 N	30.4	122 W	8.7	bad
1038	82	OCT	16	09	58	29 N	30.2	122 W	8.3	good
1039	82	OCT	16	10	59	29 N	26.9	121 W	58.2	bad, wire drag
1040	82	OCT	16	11	51	29 N	24.3	121 W	49.6	bad, wire drag
1041	82	OCT	16	12	49	29 N	21.5	121 W	39.9	good
1042	82	OCT	16	14	39	29 N	16.3	121 W	22.5	good
1043	82	OCT	16	15	41	29 N	15.0	121 W	16.7	bad, no data
1044	82	OCT	16	16	14	29 N	12.4	121 W	8.9	fair
1045	82	OCT	16	16	43	29 N	11.8	121 W	5.8	poor
1046	82	OCT	16	17	12	29 N	16.0	121 W	7.1	good
1047	82	OCT	16	17	39	29 N	19.2	121 W	8.3	good
1048	82	OCT	16	18	31	29 N	26.8	121 W	10.7	good
1049	82	OCT	16	20	11	29 N	42.2	121 W	13.6	good
1050	82	OCT	16	21	54	29 N	57.8	121 W	17.6	good
1051	82	OCT	16	22	53	30 N	6.5	121 W	19.4	poor
1052	82	OCT	16	23	31	30 N	10.9	121 W	20.2	good to 200 m
1053	82	OCT	17	00	01	30 N	14.7	121 W	20.3	good to 80 m
1054	82	OCT	17	00	28	30 N	14.0	121 W	16.9	good
1055	82	OCT	17	01	02	30 N	12.6	121 W	12.4	good
1056	82	OCT	17	01	50	30 N	07.6	121 W	03.1	good, noisy
1057	82	OCT	17	03	26	30 N	2.3	120 W	6.5	good
1058	82	OCT	17	05	08	29 N	57.4	120 W	28.9	good
1059	82	OCT	17	06	03	29 N	55.1	120 W	20.0	good to 120 m
1060	82	OCT	17	06	10	29 N	55.0	120 W	19.7	good
1061	82	OCT	17	06	46	29 N	54.2	120 W	14.4	fair, noisy
1062	82	OCT	17	07	13	29 N	53.3	120 W	10.8	good to 200 m
1063	82	OCT	17	07	47	29 N	57.4	120 W	11.6	good
1064	82	OCT	17	08	42	29 N	55.5	120 W	20.1	good
1065	82	OCT	17	10	31	30 N	8.3	120 W	14.5	good to 360 m
1066	82	OCT	17	11	36	30 N	16.7	120 W	17.0	good
1067	82	OCT	17	12	39	30 N	24.7	120 W	18.8	good
1068	82	OCT	17	14	35	30 N	40.7	120 W	21.5	good



Fig. 2. Buoy drift track and spatial survey pattern superposed on infrared satellite picture of sea surface temperature taken at 2239 GMT, 16 October 1982.

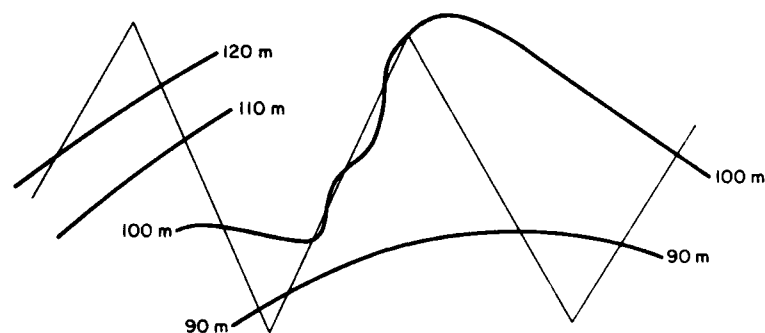


Fig. 3. Depth of the  $15^{\circ}\text{C}$  isotherm from XCP and XBT data taken during the spatial survey. XCP depths were increased by 5 m to best match XBT depths.

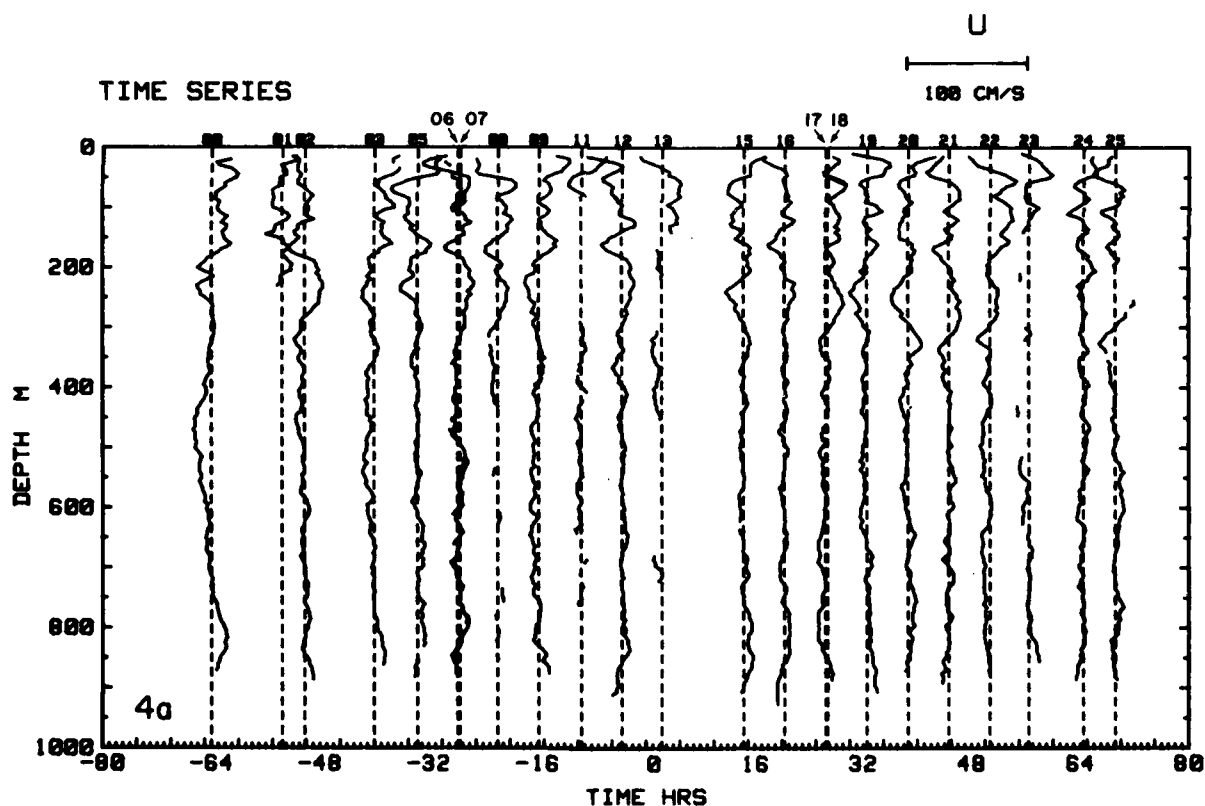
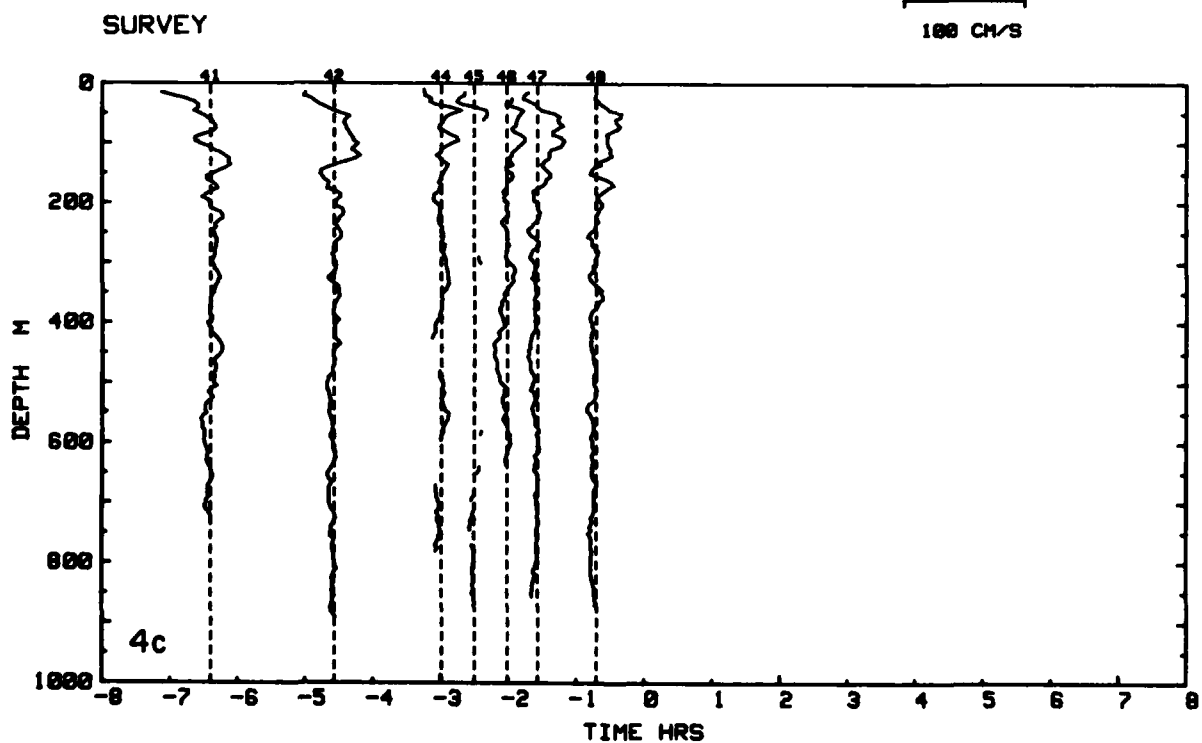
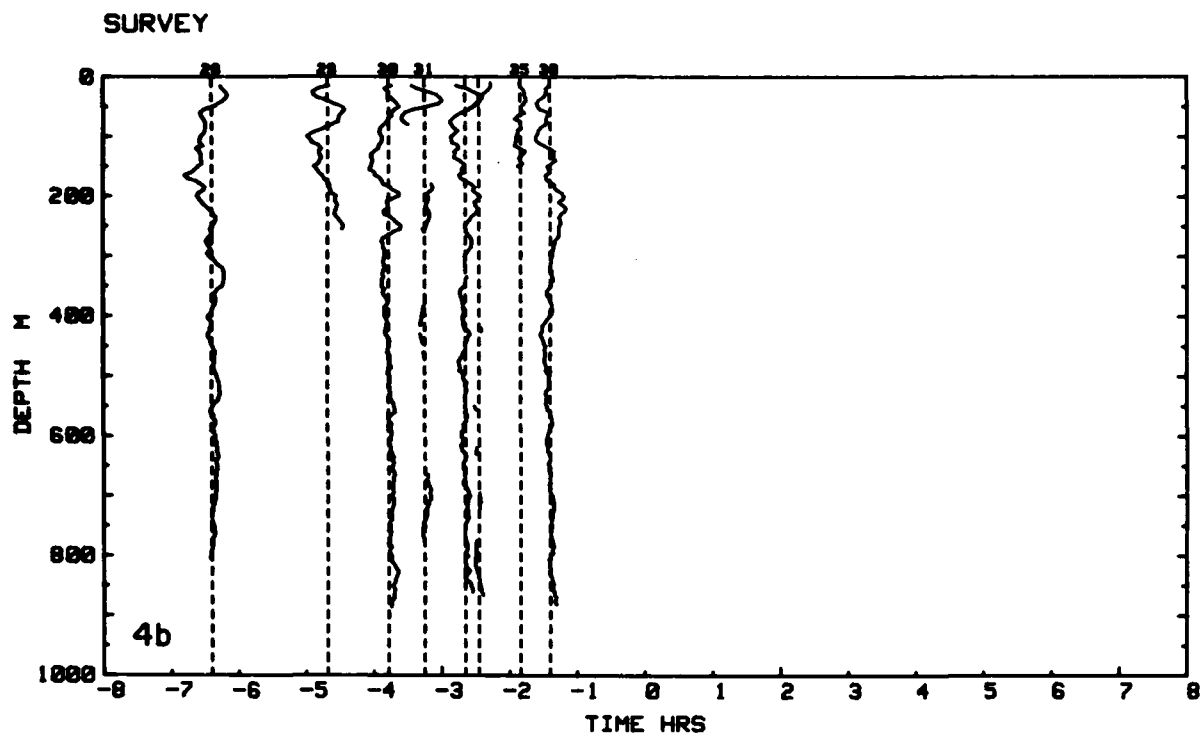
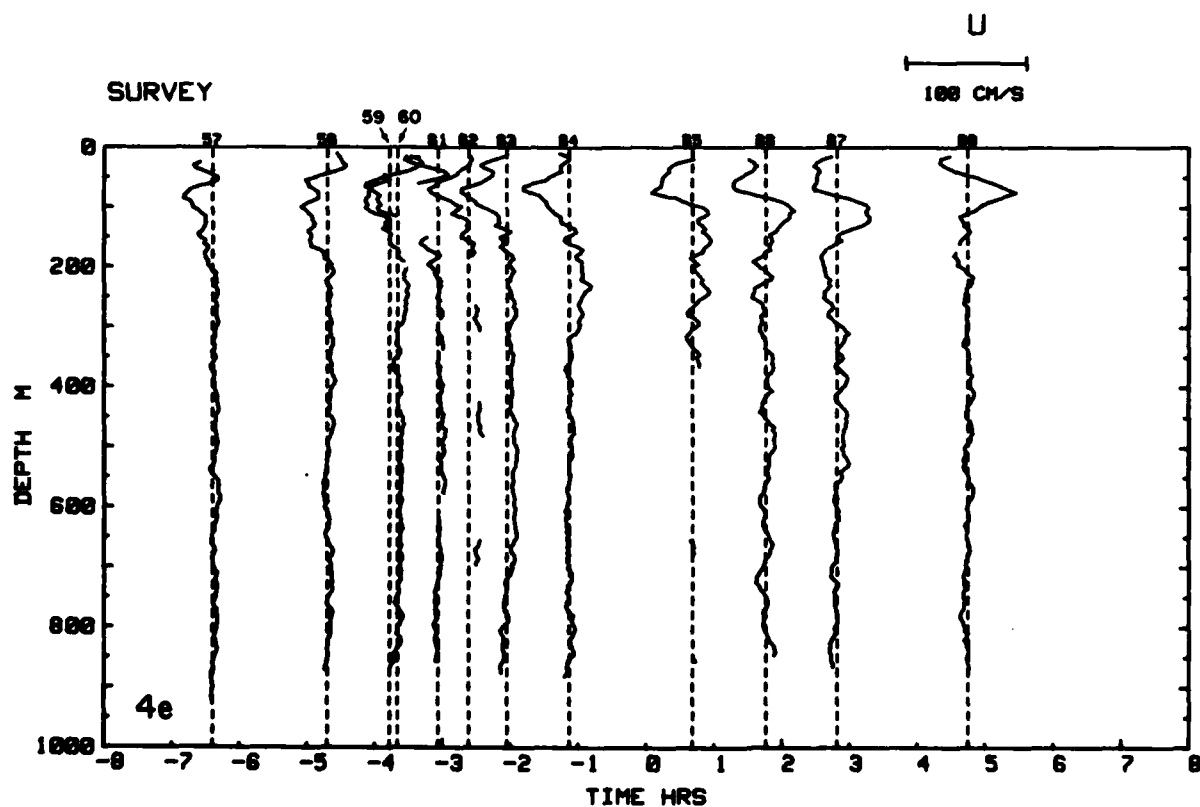
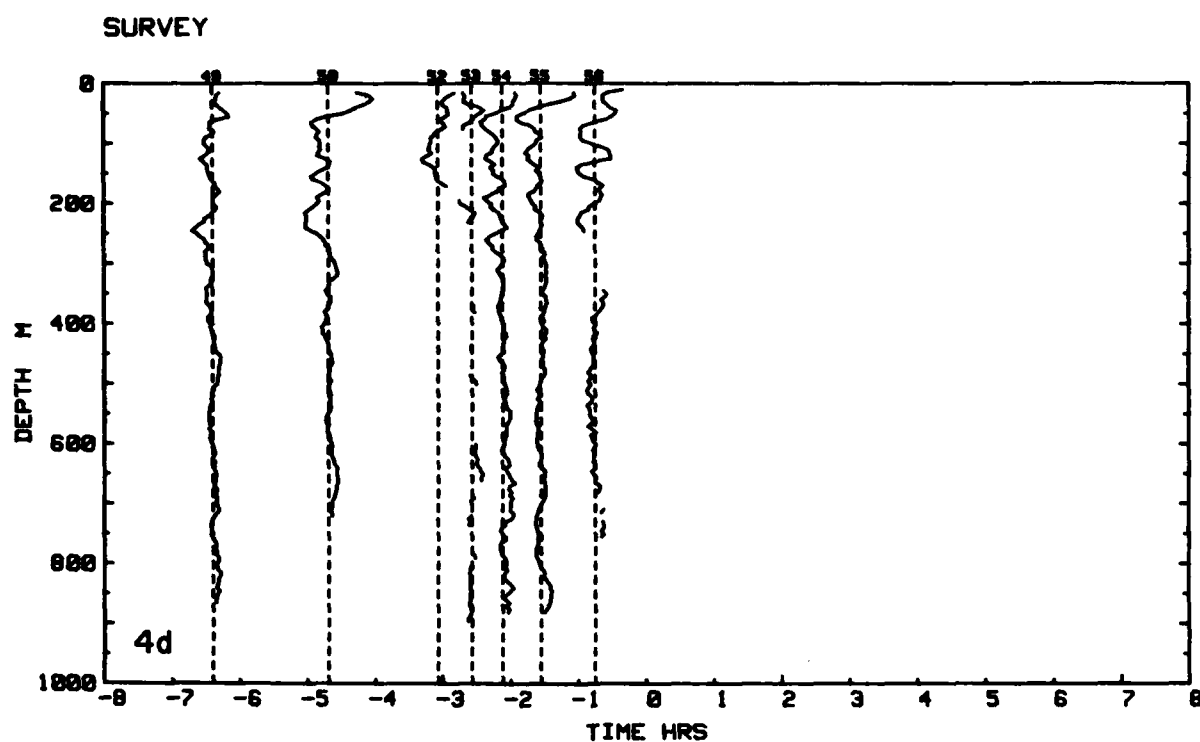


Fig. 4. East velocity component for all XCP data. Vertical dashed lines correspond to profile time relative to an arbitrary reference time displayed on the bottom axis. Profile identification numbers on the top axis correspond to the last two digits of the numbers in Tables I and II.







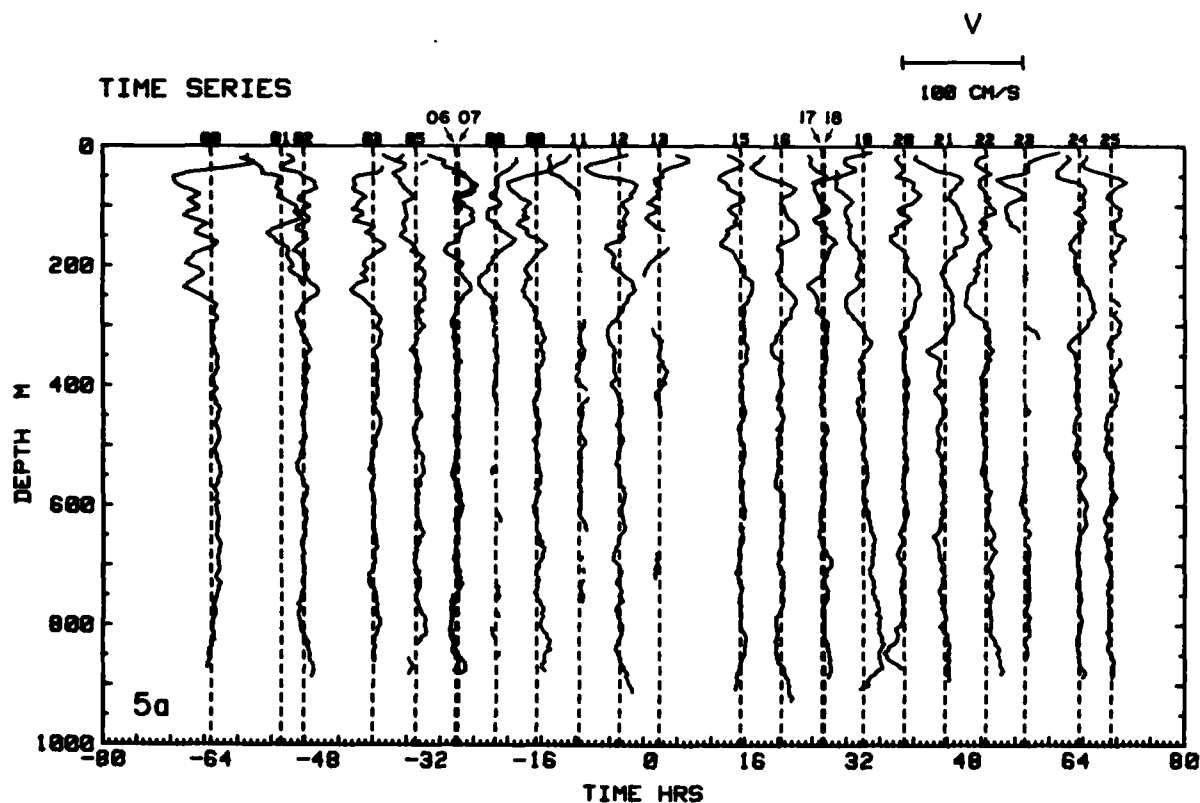
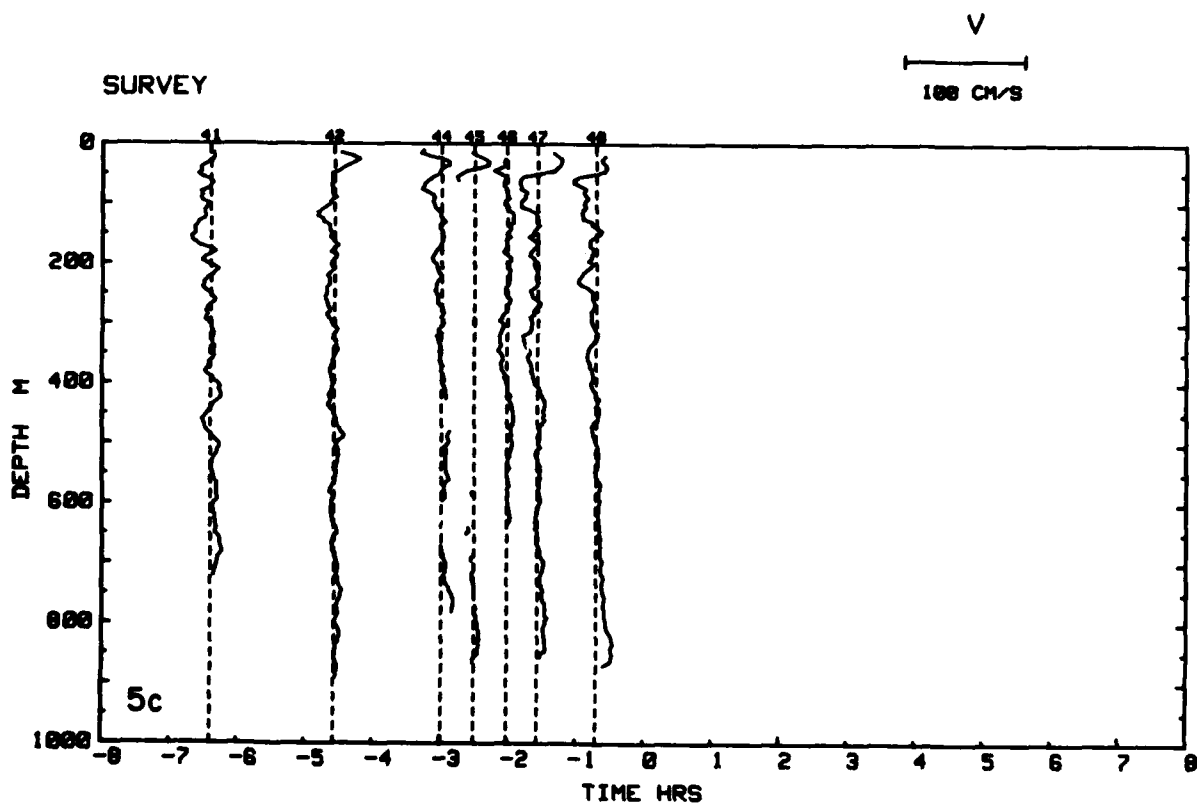
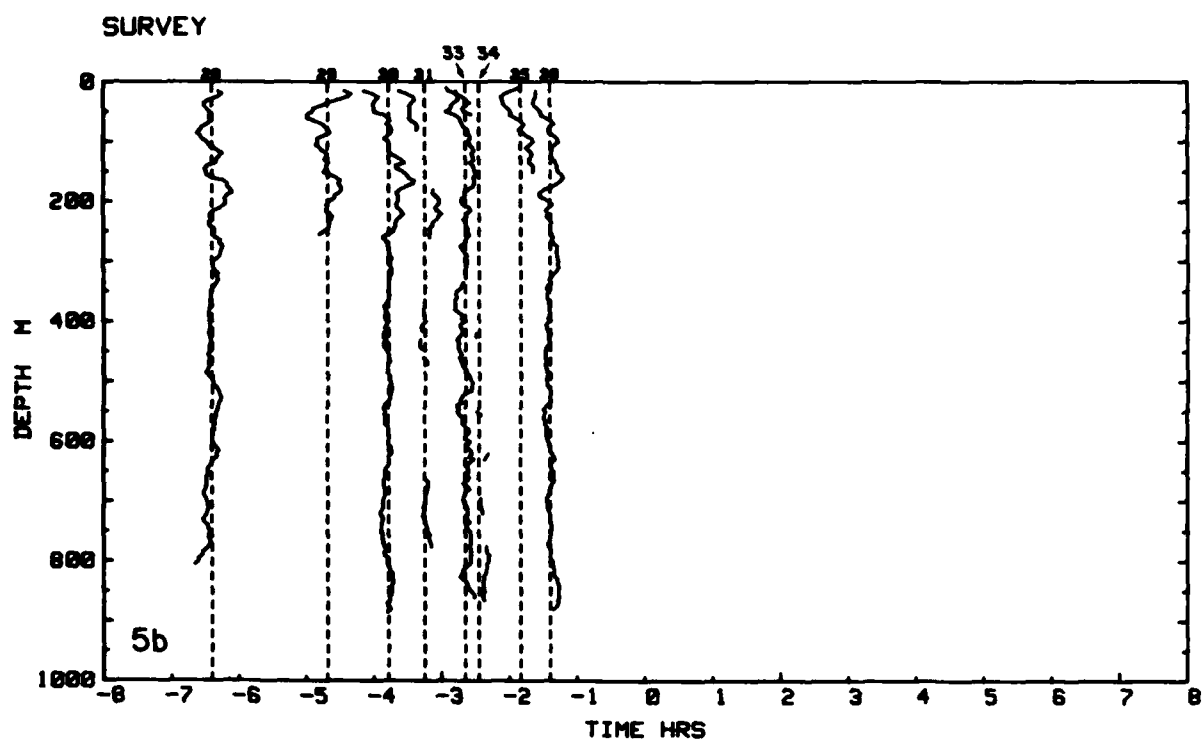
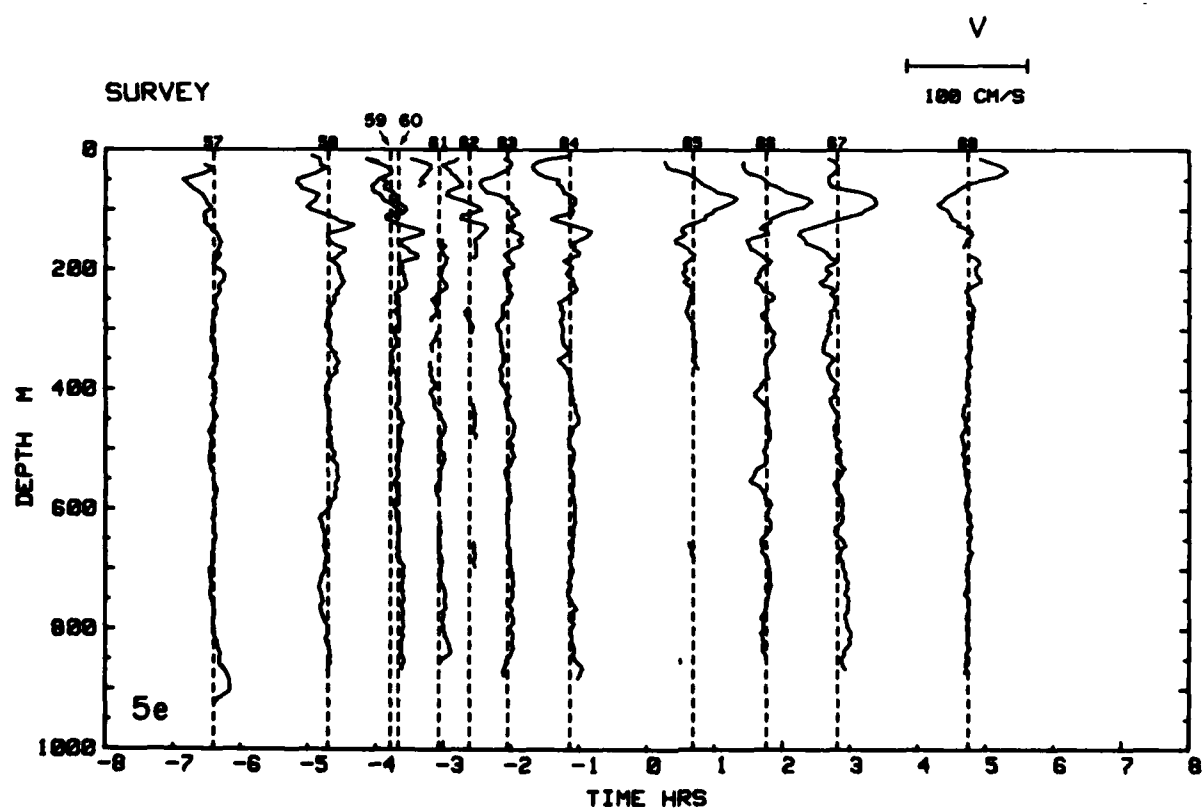
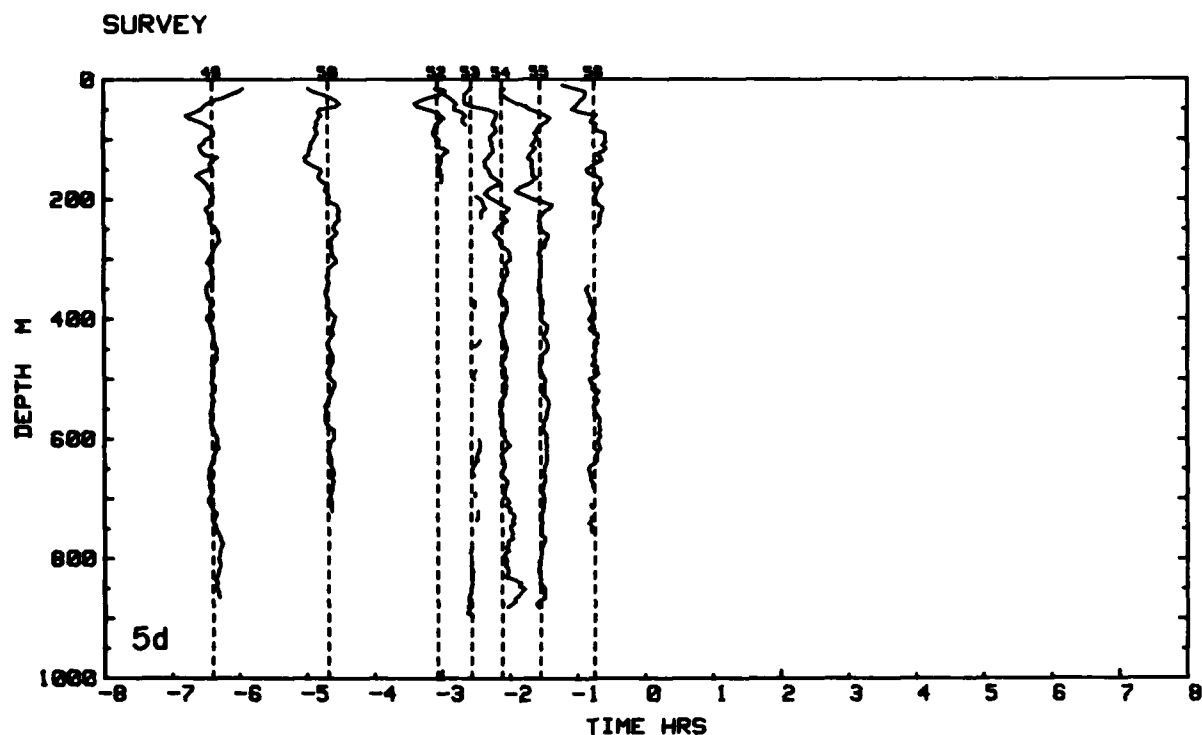


Fig. 5. North velocity component for all XCP data. Vertical dashed lines correspond to profile time relative to an arbitrary reference time displayed on the bottom axis. Profile identification numbers on the top axis correspond to the last two digits of the numbers in Tables I and II.





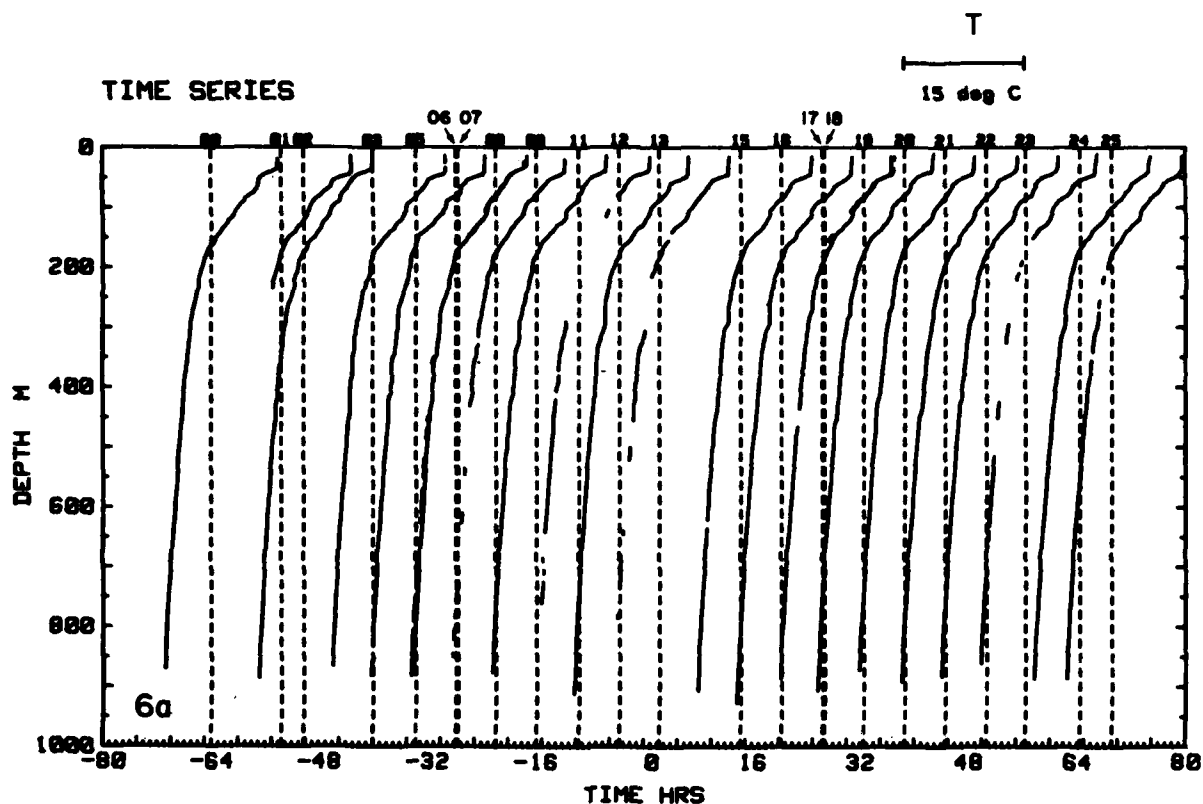
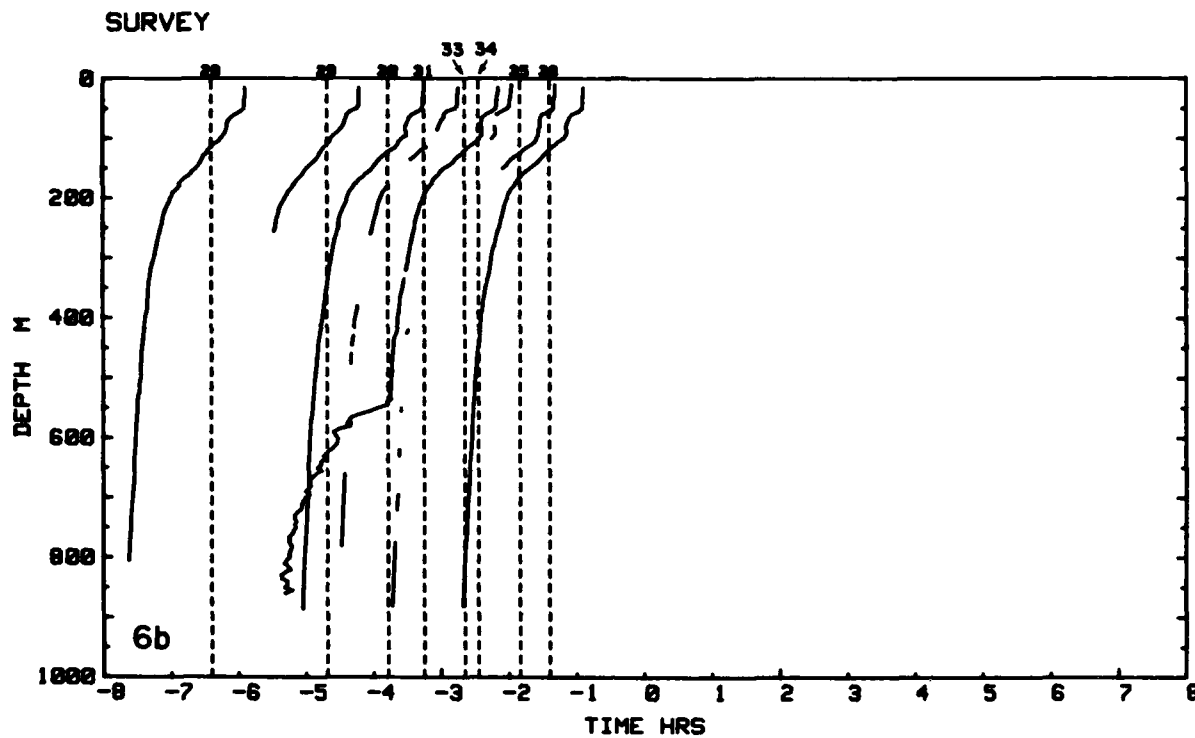
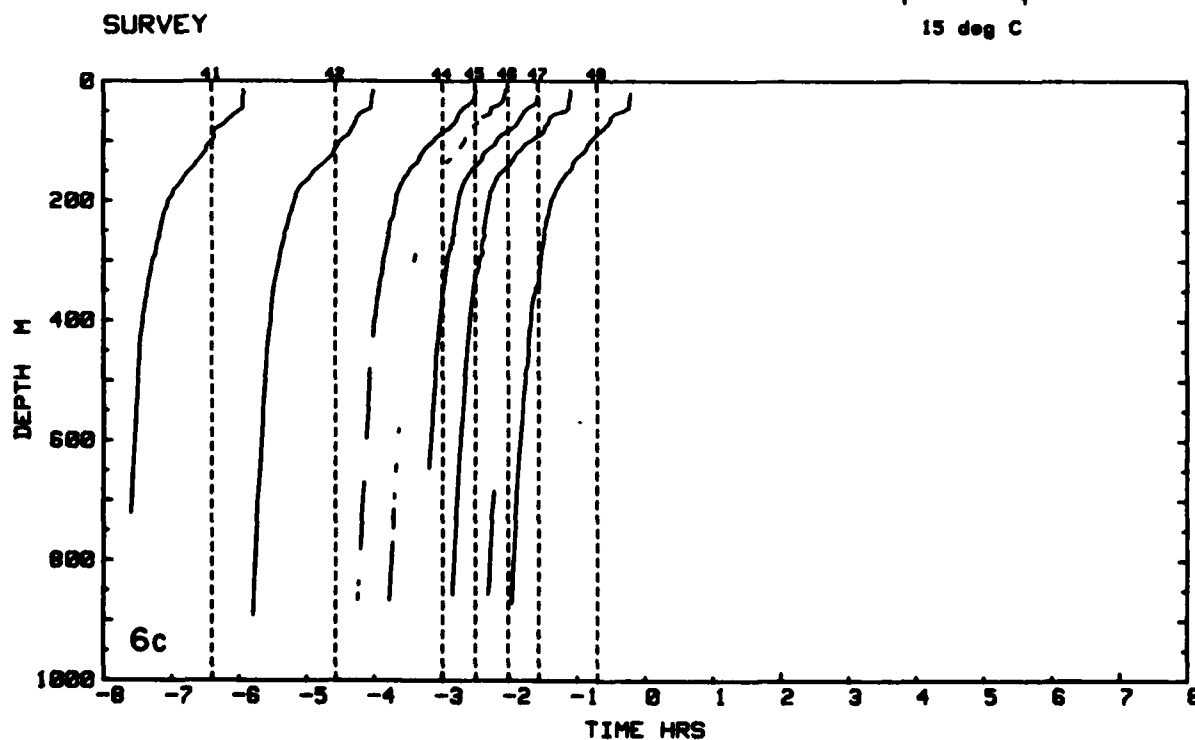
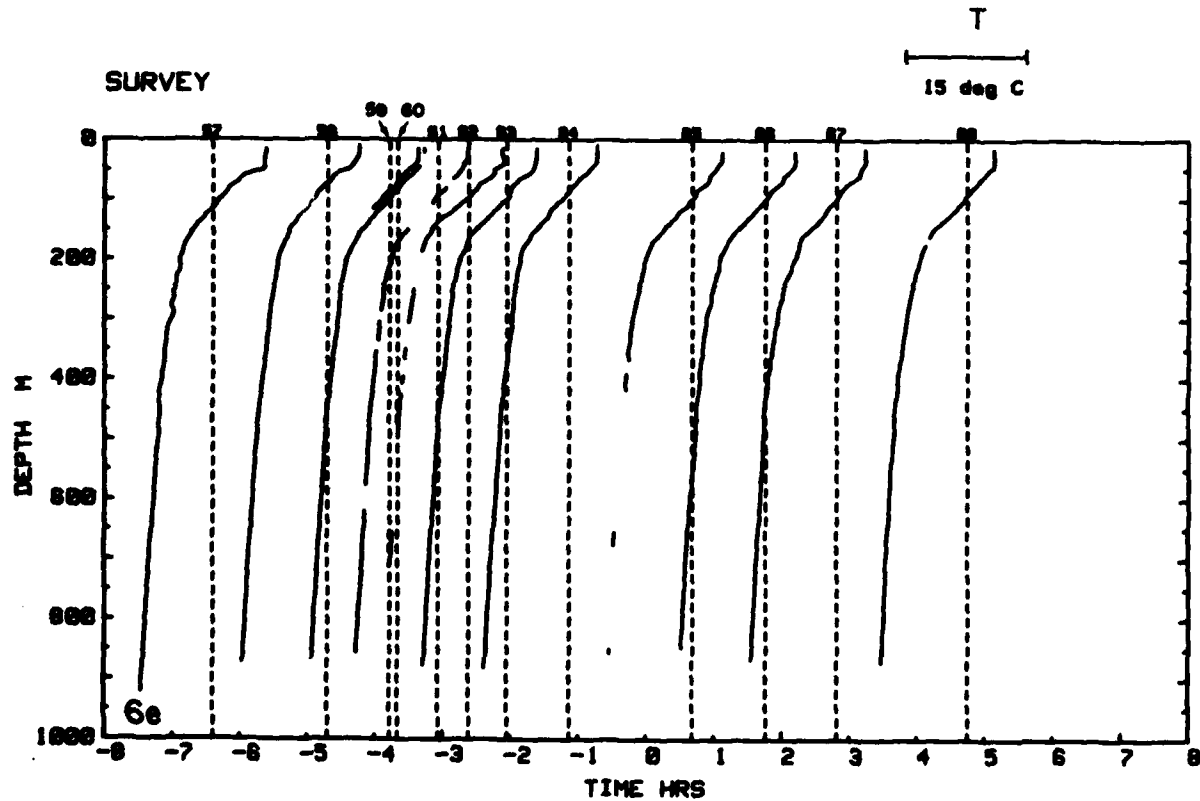
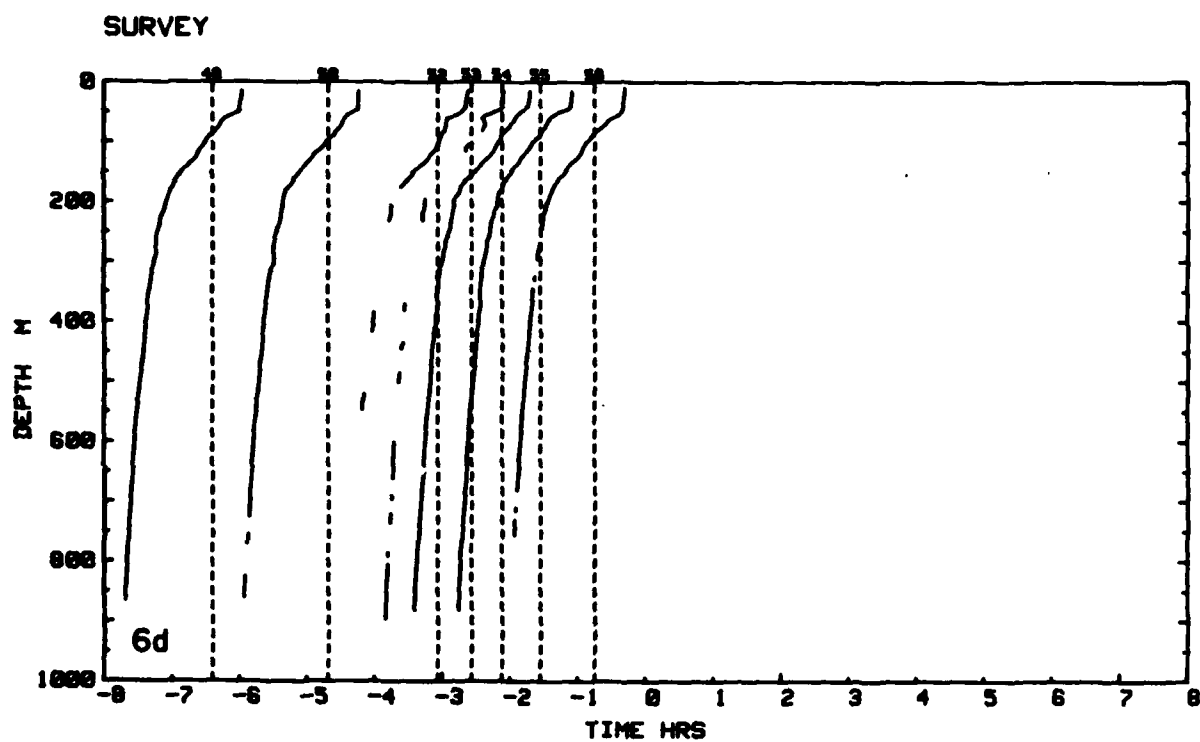


Fig. 6. Temperature profiles for all XCP data. Vertical dashed lines correspond to profile time relative to an arbitrary reference time displayed on the bottom axis. Profile identification numbers on the top axis correspond to the last two digits of the numbers in Tables I and II.



T  
15 deg C





### Discussion of data

The analysis of D'Asaro and Perkins (1983) assumes that the observed velocity profile in the ocean is dominated by clockwise rotating, inertial frequency currents. This assumption is tested in Fig. 7a. The velocity data are displayed as vectors whose base is placed at the depth of the velocity data and whose length and direction give the vector current. In addition, each velocity vector has been back-rotated to a reference time under the assumption that it is a pure clockwise rotating inertial current. The upper 400 m of the ocean is then seen to change only slowly from profile to profile, confirming the dominance of near-inertial-frequency motions. The deeper ocean shows less coherence between profiles, which suggests less inertial motion at these depths.

An energetic velocity feature is apparent in Fig. 7a between 200 m and 250 m. The velocity vector rotates anticlockwise with depth, and the feature becomes deeper with time. Following Leaman and Sanford (1975), this implies upward energy propagation in contrast to the results of the HYDRO-79 measurements. This suggests that these California Current data are different from the HYDRO-79 data taken in the Sargasso Sea and that the large excess of downward propagating energy during HYDRO-79 may not be present here.

The spatial survey data are presented in a similar format in Figs. 7b-e. Significant coherence exists between nearby profiles. It will be possible, therefore, to compute a correlation function for these data as planned. Preliminary analysis indicates that the internal wave field measured here has a somewhat larger horizontal scale than was observed during HYDRO-79 and is more inhomogeneous vertically.

The profiles taken near the end of the survey (Fig. 7e) are far more energetic than any of the others. The upper 200 m of these profiles is dominated by velocities rotating clockwise with depth, with a peak-to-peak amplitude of 70 cm/s. This feature is horizontally coherent over about 40 km, and the profiles show a strong shear across the base of the mixed layer. A similar feature was observed during FRONTS-80, but only in three isolated profiles. It is likely that these energetic near-surface, and probably inertial, features play a key role in the dynamics of the upper ocean.



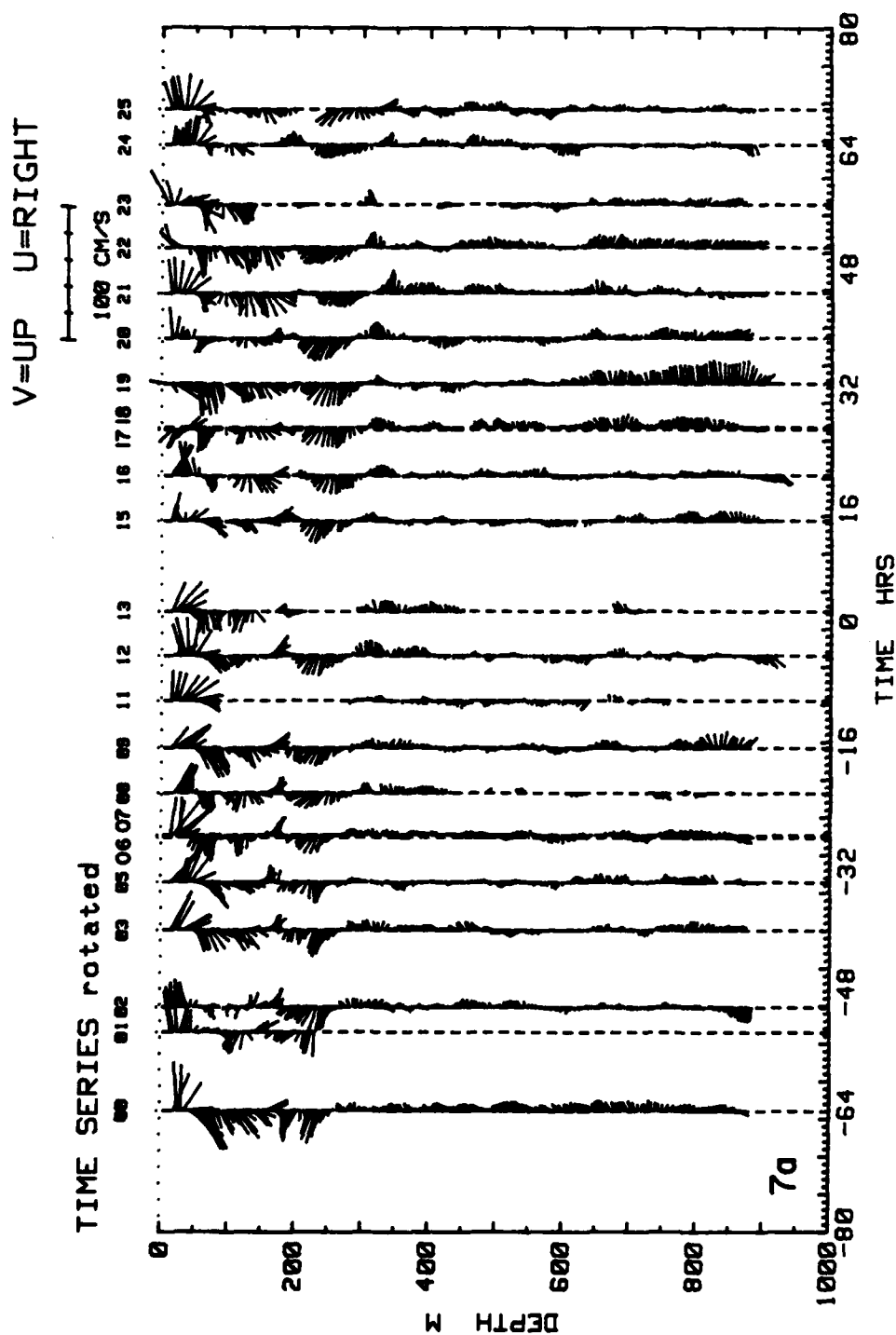
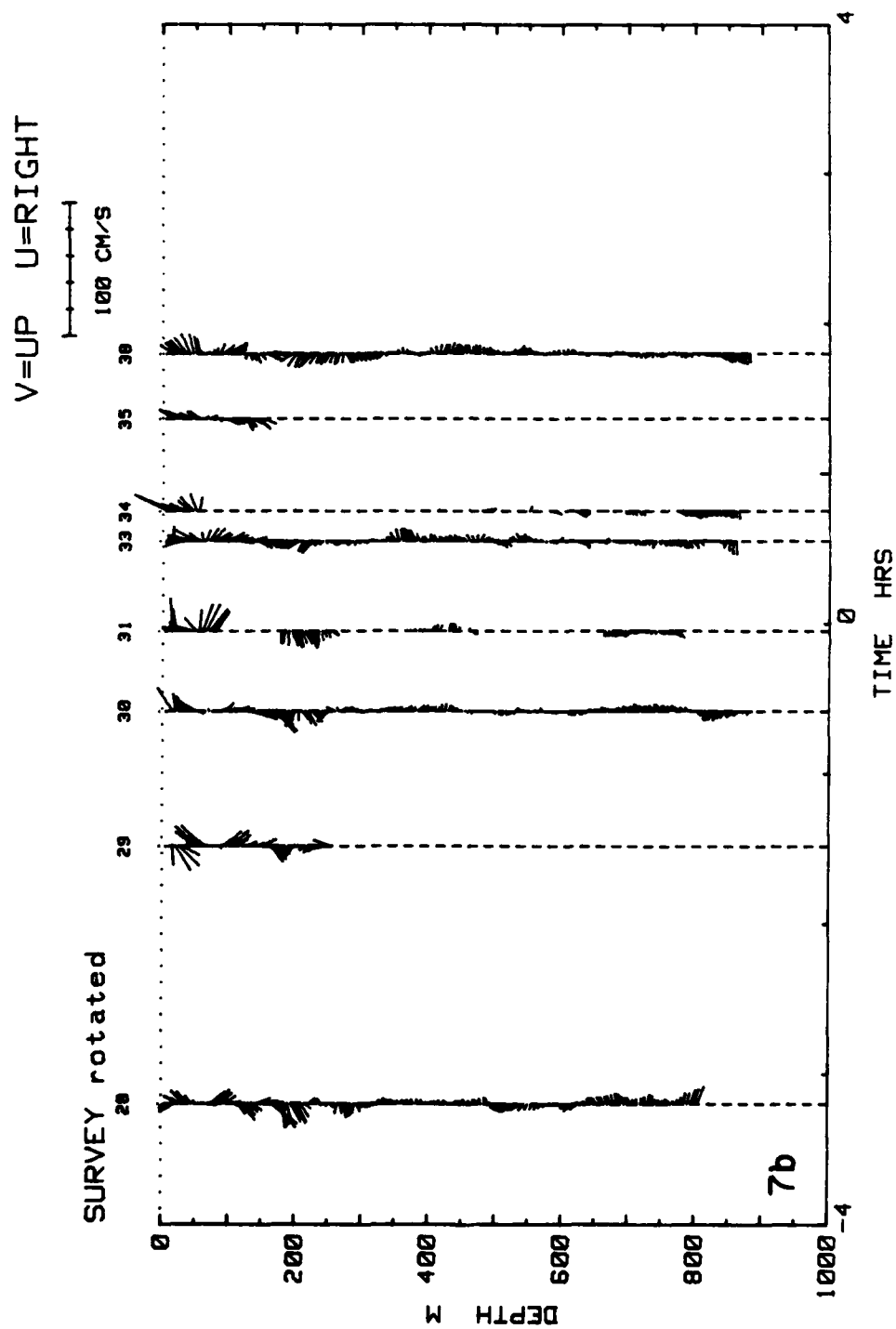
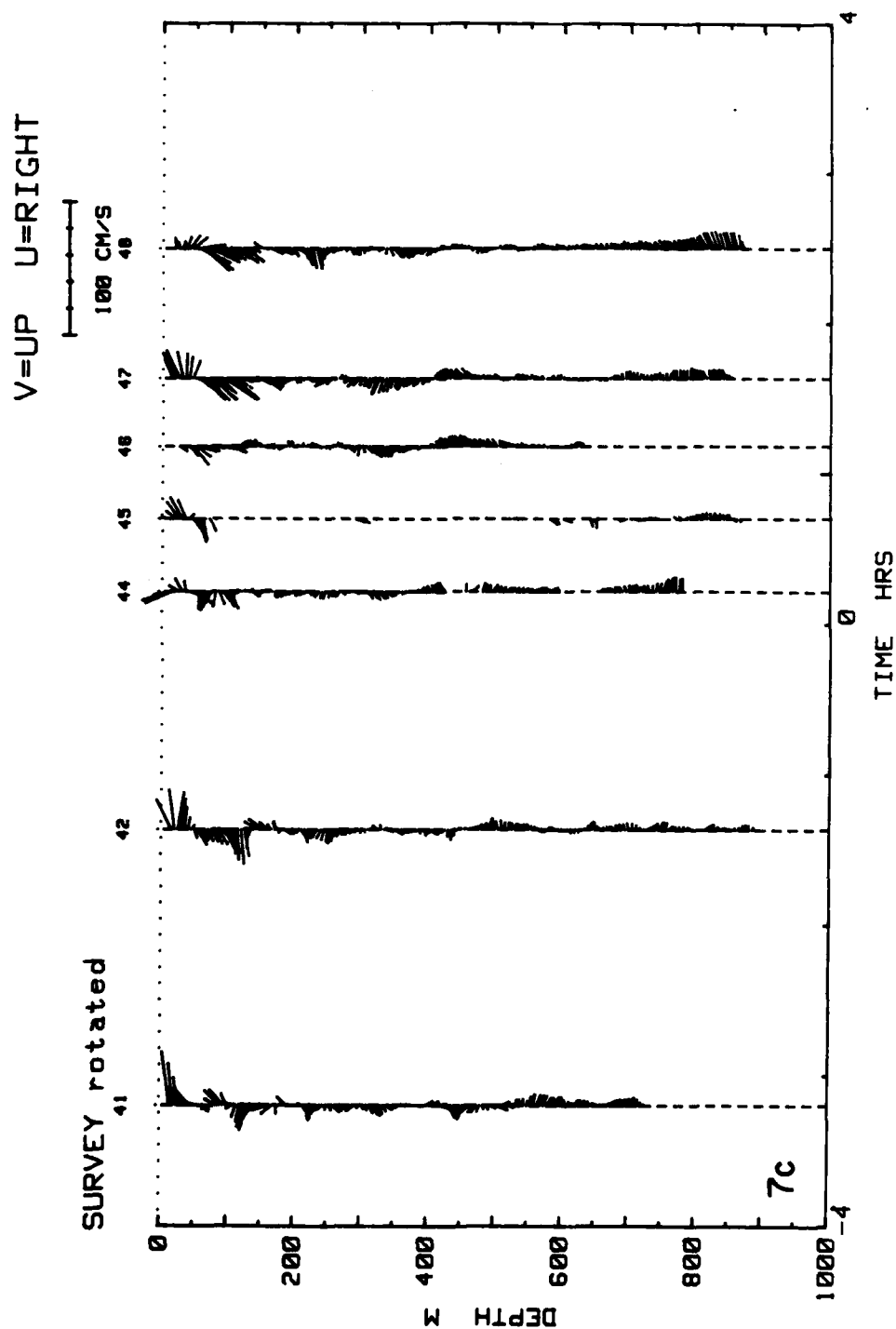
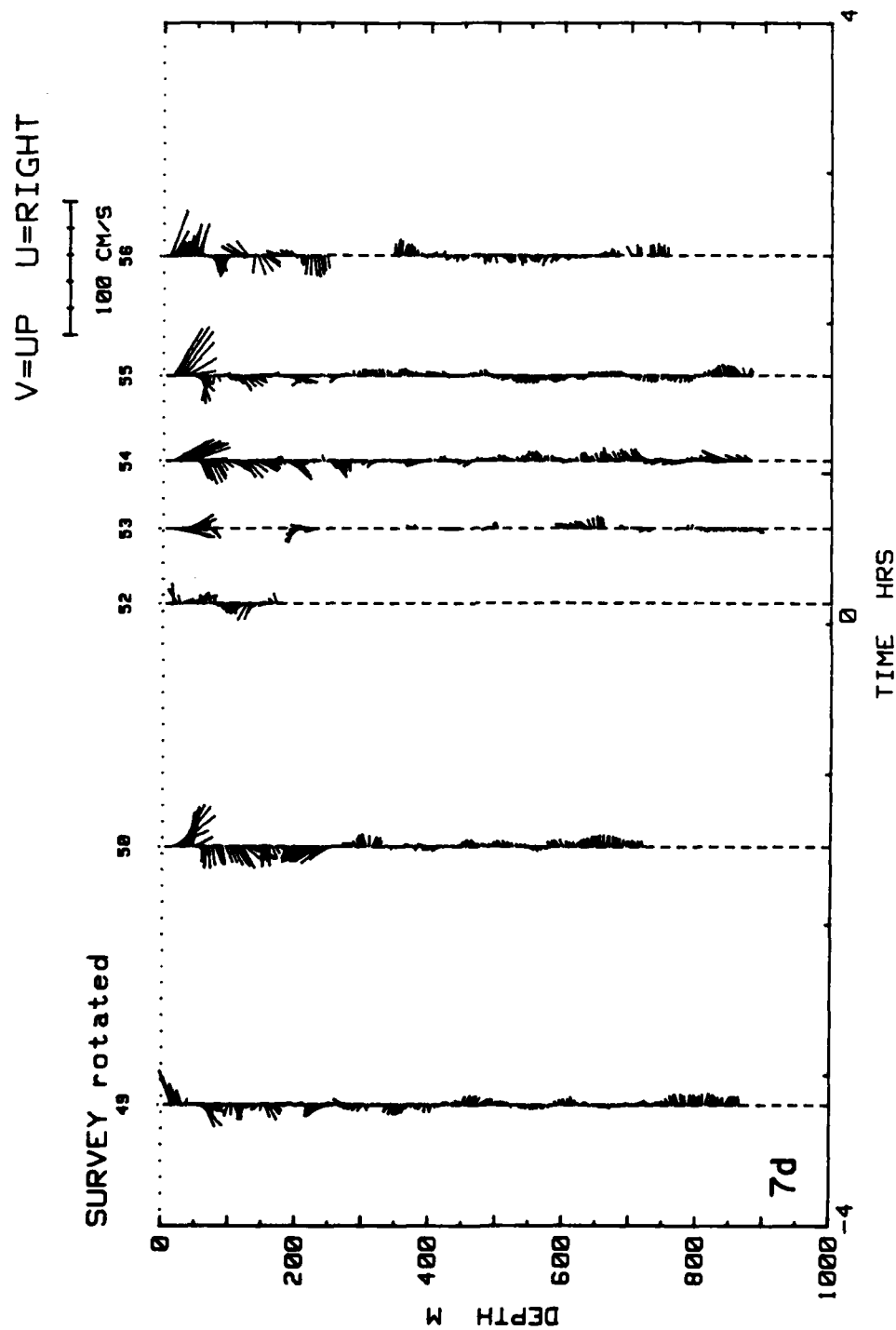
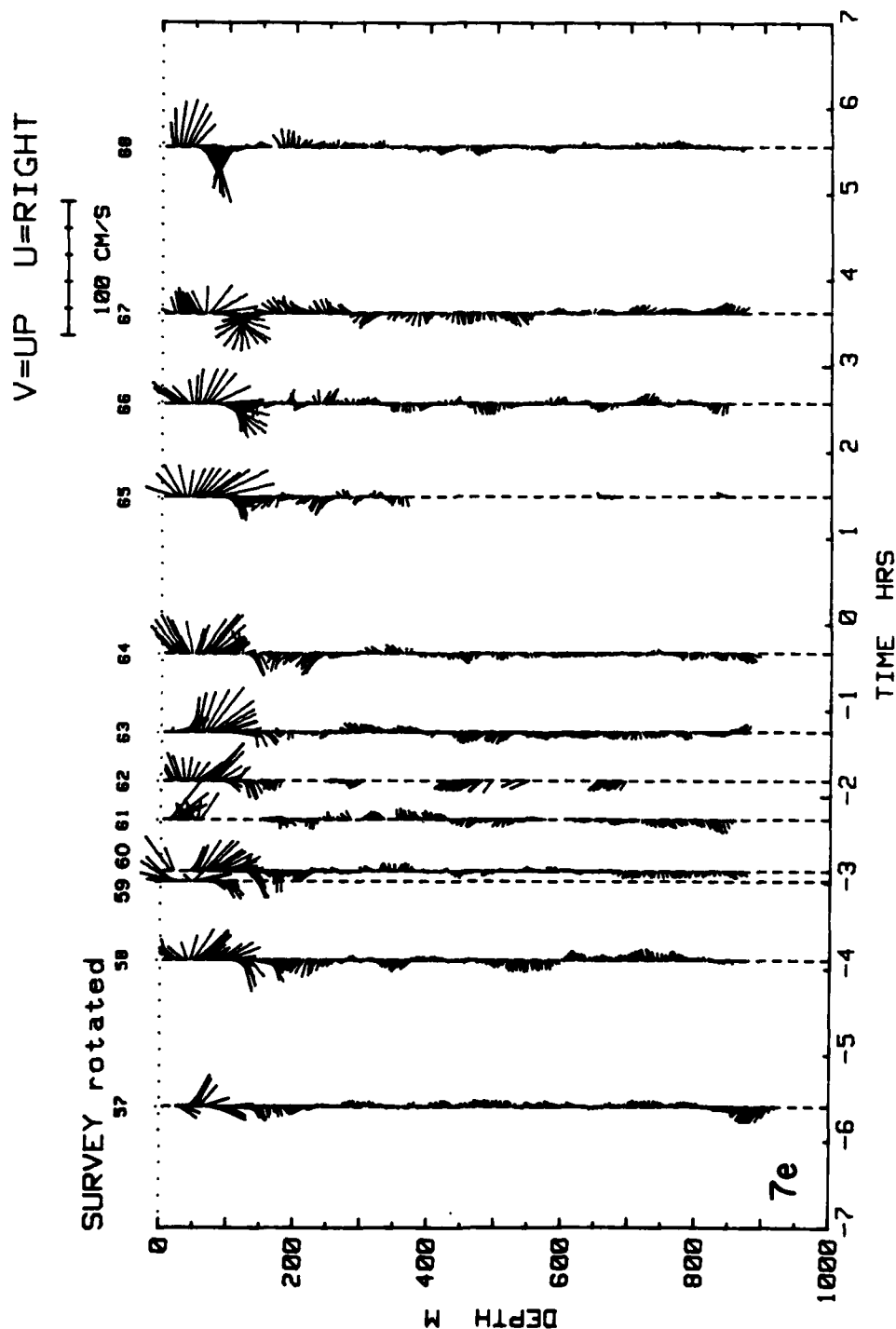


Fig. 7. Velocity vectors for all XCP data. Origin of each vector gives its depth and time on the left hand and bottom axis respectively. Each vector has been back-rotated to a reference time by assuming that it rotates clockwise at the local inertial frequency.









## RECOMMENDATIONS

To date, the XCP has been used in several dozen separate measurement programs. Based on this experience the following recommendations for its future use, particularly by NORDA, are offered. A distinction will be made between routine and specialized oceanographic measurements.

### **Routine oceanographic measurements**

Certain oceanic parameters are sufficiently important to justify an ongoing and continuous measurement program. Winds and waves are of this nature. Many years of wind and wave measurements in all oceans from many different ships allow seagoing operations to be planned anywhere with a general foreknowledge of both the typical and most severe wind and wave conditions likely to be encountered. More recently, the various XBT measurement programs have allowed the average thermal structure of the upper ocean to be known as a function of position and time over much of the ocean. Not only are these data important for operational purposes, but they also form a vital background for more detailed oceanographic studies. During 1982, for example, a pool of warm water stretching across the entire equatorial Pacific resulted in a worldwide climatic anomaly called "El Nino." The detection of this event was possible only because of the background information gathered over many years on upper ocean temperature.

### *Upper ocean shear*

The XCP is an ideal instrument for making routine measurements of upper ocean velocity and shear. These are fundamental characteristics of the upper ocean which are expected to vary vertically, geographically, and seasonally primarily because of variations in the internal wave field. The evidence to date suggests enhanced shear at the mixed layer base and enhanced shear and energy levels during stormy conditions, at particular locations within fronts, eddies, and major currents such as the Gulf Stream, and near certain topographic features such as submarine canyons. The extent of these variations, and associated variations in upper ocean Richardson number and microstructure, is largely unknown and will be determined only through a continuing measurement program.

The development of an XCP measurement program designed to characterize the variation of upper ocean shear, velocity, and Richardson number is recommended. Such a program could employ some combination of dedicated ships, ships of opportunity, or aircraft. For shipboard operations, the simplest sampling scheme would be a linear pattern

of XCP's with the separation between drops large compared to the coherence distance of the internal waves. Based on present data, separations of 100 km in the North Pacific and 40 km in the Sargasso Sea would be appropriate. Shorter separations would be used when potentially significant oceanographic features such as fronts, Gulf Stream rings, or seamounts were crossed. XBT drops, with a considerably closer spacing, would be used to detect any unexpected mesoscale features. On scientific vessels, this pattern should be supplemented with CTD casts. When more sophisticated expendable instruments such as the XCTD and XDP (Expendable Dissipation Probe) become available, these should be employed in addition to the XCP.

#### *Eddy monitoring*

The XCP can also be an important tool in the routine measurement of low frequency, geostrophic motions. At present, the major current and eddy systems off the western coasts of North America and Japan are monitored only through remotely sensed sea surface temperature and occasional XBT's. Present remote sensing techniques accurately locate oceanographic features, such as Gulf Stream rings, but give little indication of their strength. More sophisticated remote sensing capabilities, such as satellite altimetry, promise to give surface geostrophic currents, but will still not measure the vertical variation in current. The XCP, especially when combined with other techniques, offers the opportunity for monitoring these current systems throughout the upper ocean. In regions of strong low frequency motion, the high frequency, internal wave velocities are much less energetic, and generally of smaller vertical scale, than the low frequency motions. Thus, although a single XCP cast measures the sum of the low frequency, geostrophic and high frequency, internal wave velocity profiles, a low order polynomial fit to the XCP velocity profile generally measures the low frequency velocity profile to within about 5 cm/s. Used in this way, the XCP can replace CTD computations of dynamic height as a method for obtaining relative velocity profiles.

The XCP would allow the creation of a routine program to monitor energetic eddy regions. Such a program could employ either shipborne or airborne XCP's and function simultaneously as a part of the upper ocean shear program outlined above. Remote sensing would be used to direct a ship or plane to a previously identified feature, a Gulf Stream ring for example. A section of XCP's would then be made across the ring. This would be done for many different features over time, resulting in a continuous record of the strength of the strong mesoscale features in the operational area.

**Specialized scientific measurements**

Velocity is a basic oceanographic variable that is difficult to measure from a ship. The XCP provides this capacity and therefore has a great many applications in oceanographic research. In particular, the XCP has been shown to be a useful tool in internal wave studies, such as the one described in this report. Opportunities for future internal wave research using the XCP include:

- (1) Oceanic response to strong storms, both midlatitude cyclones and hurricanes. This is probably best done using AXCP's, both because of their mobility, which allows the measurements to be placed optimally with relation to the storm, and because they are less affected by the high sea states within storms than ship-launched XCP's.
- (2) Internal wave interaction with low frequency flows. Present evidence suggests a strong transfer of energy between mean flows and internal waves whose magnitude is important for the dynamics of both. The details of this interaction are not well known and deserve further investigation. In addition, it is expected that spatially varying mean flows will greatly modify the generation of internal waves by topography or wind.
- (3) Internal wave interaction with topography. Both theory and observation suggest enhanced generation and dissipation of internal waves on topographic features, especially in the presence of a low frequency flow.

The sampling strategy for investigating these subjects will depend on the goals of a particular measurement program. However, a mix of spatial and temporal measurements such as those described in this report will probably be used in a great many cases. The design elements outlined in this report are likely to be useful in such future measurements.



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  <b>Sixty-nine profiles of horizontal velocity and temperature from the surface to about 800 m were made using the Expendable Current Profiler (XCP) during De Steiguer cruise 1212, 7-18 October 1982. The XCP's were deployed in a 6 day time series behind a drogued buoy and in a 275 n.mi. zigzag spatial survey. Satellite infrared images were used to locate a cruise area away from strong mesoscale features. The measurements were designed to estimate the horizontal coherence function of the near-inertial</b>		

frequency internal wave field for comparison with similar measurements made in the Sargasso Sea. It was found that the near-inertial waves are a dominant feature of the velocity field. Significant coherence exists between nearby profiles. It will, therefore, be possible to compute a correlation function for these data as planned. A near-surface feature with peak-to-peak velocities of 70 cm/s was observed and partially surveyed.

